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THESIS

OPTIMIZING PROCUREMENT PLANNING OF NAVY SHIPS AND AIRCRAFT

by

Nihat Baran

December 2000

Thesis Advisor:	Robert F. Dell
Second Reader:	Gerald G. Brown

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REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2000	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Title (Mix case letters)
Optimizing Procurement Planning of Navy Ships and Aircraft

5. FUNDING NUMBERS

6. AUTHOR(S) Baran, Nihat

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief of Naval Operations, Assessment Division (N81)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

The United States Navy Chief of Naval Operations Assessment Division (N81) is responsible for planning long-range capital expenditure on ships, submarines and aircraft. This planning is complicated, involves billions of dollars over decades, and determines future Navy capability. Navy force structure analysts have to balance: yearly budgets; requirements, current inventory, and procurement options for ships, submarines, and aircraft; and capacity and workforce levels of shipyards and factories. N81 Navy analysts currently use the Extended Planning Annex/Total Obligated Authority (a spreadsheet that estimates the financial impact of any complete future plan) to assist them with their complex planning. The Capital Investment Planning Aid (CIPA) is a prototypic optimization model, limited in scale, previously developed to demonstrate the benefits of augmenting EPA/TOA with optimization. This thesis introduces Generalizing Procurement Planning for Naval Ships and Aircraft (GENSA), which extends CIPA. GENSA is tested with a 30-year planning horizon with 29 mission areas, 45 ship classes, 39 aircraft types, 13 production facilities, and four categories of money. A current base case and an excursion demonstrate GENSA can be used to address exigent issues optimally.

14. SUBJECT TERMS
Integer Linear Programming, Military Capital Budgeting, Optimization, Force Structure

15. NUMBER OF PAGES 72

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OPTIMIZING PROCUREMENT PLANNING OF NAVY SHIPS AND AIRCRAFT

Nihat Baran
Lieutenant Junior Grade, Turkish Navy
B.S., Turkish Naval Academy, 1995

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
December 2000

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ABSTRACT

The United States Navy Chief of Naval Operations Assessment Division (N81) is responsible for planning long-range capital expenditure on ships, submarines and aircraft. This planning is complicated, involves billions of dollars over decades, and determines future Navy capability. Navy force structure analysts have to balance: yearly budgets; requirements, current inventory, and procurement options for ships, submarines, and aircraft; and capacity and workforce levels of shipyards and factories. N81 Navy analysts currently use the Extended Planning Annex/Total Obligated Authority (a spreadsheet that estimates the financial impact of any complete future plan) to assist them with their complex planning. The Capital Investment Planning Aid (CIPA) is a prototypic optimization model, limited in scale, previously developed to demonstrate the benefits of augmenting EPA/TOA with optimization. This thesis introduces Generalizing Procurement Planning for Naval Ships and Aircraft (GENSA), which extends CIPA. GENSA is tested with a 30-year planning horizon with 29 mission areas, 45 ship classes, 39 aircraft types, 13 production facilities, and four categories of money. A current base case and an excursion demonstrate GENSA can be used to address exigent issues optimally.

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ACKNOWLEDGMENTS

I extend my sincere thanks and appreciation to the following individuals.

To my thesis advisors, Professors Robert Dell and Gerald Brown, for their guidance, advice, patience and overall assistance accomplishing my last and most important learning experience at NPS. I really enjoyed and learned a lot working with them.

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EXECUTIVE SUMMARY

The United States Navy Chief of Naval Operations Assessment Division (N81) prepares and justifies plans for long-range capital expenditure on ships, submarines and aircraft. These plans are important and by their nature complicated: They involve spending billions of dollars over decades and they have a profound impact on the future effectiveness of the Navy. These plans have to consider capacities of shipyards and factories, and they must rationalize and reconcile the continued interoperability of the net result of all decisions over time.

N81 currently uses a spreadsheet-based decision support tool for capital planning called Extended Planning Annex/Total Obligated Authority (EPA/TOA). EPA/TOA was commissioned by N81 to estimate the full cost of procuring and operating a complete long-term force structure. EPA/TOA is a descriptive model, and given an input of a complete spending plan, EPA/TOA yields an accounting of the estimated long-run cost of this plan using generally accepted cost forecasting methods. Unfortunately, preparing a force structure scenario in EPA/TOA is labor-intensive work, so preparing many competing scenarios in search of long-range improvement is not feasible given the time pressure always governing this planning.

Capital Investment Planning Aid (CIPA) has been developed for N81 as an optimization-based decision support tool. Given an input of long-range force structure requirements, costs and rules governing candidate procurements and retirements of major weapons systems, and other planning guidance, CIPA suggests an optimal portfolio of investments and actions. CIPA has been prototypically demonstrated for a 25-year plan with a realistic subset of US Navy ships, submarines and aircraft, and a representative subset of budget funding categories.

Generalizing Procurement Planning for Naval Ships and Aircraft (GENSA), the subject of this study, extends CIPA to include additional Navy ship classes and aircraft types, and incorporates the Manpower Navy (MPN) funding category not considered by CIPA. GENSA has a planning horizon of 30 years, 29 mission areas, 45 ship classes, 30 aircraft types, and 13 production facilities. GENSA follows CIPA in recognizing cost categories Ship Conversion Navy (SCN), Aircraft Procurement Navy (APN), and

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Operating Maintenance Cost Navy (OMN), and adds MPN. The goal of GENSA is to provide an omniscient long-term plan that considers so much high-fidelity detail that the post-optimization analysis with EPA/TOA will be much easier.

I. US NAVY CAPITAL BUDGETING FOR SHIPS AND AIRCRAFT

The United States Navy Chief of Naval Operations Assessment Division (N81) prepares and justifies plans for long-range capital expenditure on major Navy weapons systems, such as ships, submarines and aircraft. These plans are important: they commit spending of billions of dollars over decades, and they have a profound impact on the force structure and effectiveness of the future Navy. These plans are by their nature complicated: they consider the influence over time that major procurements have on shipyards and factories, they evaluate the potential contributions of new war fighting and manufacturing methods and technologies, and they must rationalize and reconcile the continued interoperability of the net result of all decisions over time.

N81 uses a spreadsheet-based decision support tool for capital planning called Extended Planning Annex/Total Obligated Authority (EPA/TOA) [System Planning and Analysis 2000]. EPA/TOA was commissioned by N81 to estimate the full cost of procuring and operating a complete long-term force structure. EPA/TOA is a descriptive model, and given an input of a complete procurement and retirement plan, EPA/TOA yields an accounting of the estimated cost of this plan using generally accepted cost forecasting methods. Unfortunately, preparing complete candidate long-range capital plans is labor-intensive work, so preparing many competing scenarios in search of long-range improvement is not feasible given the time pressure always governing this planning.

Capital Investment Planning Aid (CIPA) has been developed for N81 as an optimization-based decision support tool, and given an input of long-range force structure requirements, costs and rules governing candidate procurements and retirements of major weapons systems, and other planning guidance, CIPA suggests an optimal portfolio of investments and actions [Field 1999]. The motivation of CIPA is to offer an omniscient long-term starting point for detailed, myopic local analysis and adjustment with EPA/TOA. CIPA has been prototypically demonstrated for a 25-year plan with a realistic subset of US Navy ships, submarines, and aircraft, and a representative subset of budget funding categories.

Generalizing Procurement Planning for Naval Ships and Aircraft (GENSA), the subject of this thesis, extends CIPA to include additional Navy ship classes and aircraft types, and incorporates the Manpower Navy (MPN) funding category not considered by CIPA. The goal of GENSA is to provide an omniscient long-term plan that considers so much high-fidelity detail that the post-optimization analysis with EPA/TOA can be reduced.

II. HOW THE NAVY PLANS ITS CAPITAL BUDGET

A. IWAR FORCE STRUCTURE ANALYSIS

Warfare Architecture Assessment Planning Process (IWAR) was adopted by the Navy in 1998 to improve overall Navy program planning by establishing a single organization to develop comprehensive, end-to-end analysis of warfare capabilities [US Navy 2000]. Force Structure is one the supporting components of IWAR. Force Structure focuses on "assisting Navy leadership (to) best match available resources, with desired capabilities, in the near, middle, and far terms." Force Structure analyzes alternate procurement and retirement plans for ships, submarines and aircraft within fiscal year budgets. A primary Force Structure goal is to quantify the effect of Ship Conversion Navy (SCN) and Aircraft Procurement Navy (APN) programs in terms of dollars and capability.

B. EPA/TOA, VAMOSC, AND THEIR COST ESTIMATES

N81 uses EPA/TOA [System Planning Analysis 2000] for IWAR Force Structure analysis. EPA/TOA is a descriptive spreadsheet model that estimates the cost of a specified scenario, including the procurement cost of a given force structure and the operating cost of this force structure over predefined service lives. EPA/TOA uses many of the estimates of costs and cost interdependence among systems from a normative statistical analysis of Naval Visibility and Management of Operating and Support Costs (VAMOSC) [Kelly 2000a]. Naval Center For Cost Analysis [2000] describes VAMOSC.

C. HOW EPA/TOA IS USED

N81 typically uses EPA/TOA by carefully tending a few alternate base cases that are each completely fixed for the first five years. For casual identification, such a base case might be named, for instance, RAD6, after the EPA/TOA Resource Allocation Display feature that is used to express the scenario, and the scenario number. To respond to some emergent question, N81 selects a referent base case and an excursion might involve changing the quantity and/or procurement schedule in SCN (or in APN) and then observing the financial impact over some planning horizon [Burton 2000]. This is error prone because alterations to SCN or APN procurement plans require synchronous changes to many spreadsheets and manual checks to confirm that force structure requirements are still met, that capacity of industrial facilities is still used efficiently, and that all the other nuances of the seminal base case are retained.

D. CAPITAL INVESTMENT PLANNING AID (CIPA)

Capital Investment Planning Aid (CIPA) is an optimization-based decision support tool to help Navy planners improve long-range capital budgeting for force structure [Field 1999]. GENSA extends CIPA and shares all attributes of CIPA described below.

CIPA imitates the data and cost estimating assumptions of EPA/TOA. However, CIPA also considers *as input* budget restrictions, capacity of production facilities, force level requirements, and other planning guidance. CIPA employs a mixed-integer linear program that explores all feasible alternate candidate plans, and recommends purchase years and quantities for a 25-year planning horizon covering eight mission areas, 19 ship classes, five aircraft types, five production facilities, and three categories of money. CIPA replaces much of the manual work required to prepare complete scenarios for EPA/TOA, and the optimization can be used to suggest alternate plan portfolios more rapidly than a manual analysis could expect to discover with EPA/TOA. Finally, CIPA mimics good manual planning practice by looking for opportunities to improve the quality of plans by allowing constraint violations as long as the cost of these violations can be more than repaid elsewhere. For instance, with individual ships costing billions of dollars, cases arise where violating an annual ship construction budget by a few million dollars is amply rewarded within a year by avoiding the cost and disruption of a delay that is otherwise unjustified.

CIPA inputs include annual force level requirements by class of ship or type of aircraft, minimal and maximal industrial facility utilization for producing ships and submarines, scheduled retirement deadlines from EPA/TOA, and annual lower and upper limits on Total Obligated Authority (TOA). CIPA recognizes budgets in three categories: Ship Conversion Navy (SCN), Aircraft Procurement Navy (APN), and Operating Maintenance Cost Navy (OMN).

CIPA permits any portion of the capital plan to be fixed, so it is easy to fix the first five years imitating an EPA/TOA base case. Procurement costs follow a specified pattern that might start a year or two before production and extend through the year of production. OMN costs are incurred for the entire year of delivery. Aircraft are delivered two years after procurement.

CIPA expresses key constraints as elastic goals [e.g., Brown, Dell, and Wood 1997]. These goals may be violated, but such violation inflicts a linear penalty cost per unit of violation. Further, these goals may be expressed cumulatively, so that any violations that arise in the course of the planning horizon persist over time and continue to inflict penalties until they are corrected. CIPA treats the TOA budget band, limits on production facility utilization, and mission inventory targets as goals. CIPA evaluates procurement and retirement plans by minimizing the present value of the sum of all penalties inflicted over the planning horizon. CIPA recommends an optimal portfolio of annual procurements and retirements over a planning horizon typically extending 25 years. As a practical matter, while the length of this planning horizon is limited by the ability to forecast future requirements and alternatives, it exceeds the useful life of weapons systems under consideration.

E. MILITARY CAPITAL BUDGETING LITERATURE

Field [1999] presents a literature review that is still current at this writing.

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III. OPTIMIZING PROCUREMENT PLANNING OF NAVY SHIPS AND AIRCRAFT

A. GENERALIZING PROCUREMENT PLANNING AND EXTENSIONS OF CIPA

GENSA generalizes CIPA in several ways. GENSA considers additional ship classes and aircraft types that the US Navy currently operates or anticipates operating. GENSA has a planning horizon of 30 years (FY01-FY30, where FY01-05 are fixed), 29 mission areas, 45 ship classes, 30 aircraft types, and 13 production facilities. GENSA follows CIPA in recognizing cost categories SCN, APN, and OMN. Table 1 summarizes CIPA mission areas and related ship, submarine and aircraft types. Tables 2 and 3 present SCN and APN mission areas introduced by GENSA.

Mission Areas	**Ship Classes And Aircraft Types**
Destroyers	FFG, DDG, DD, DD21
Cruisers	CG
Carriers	CVN63, CVN65, CVN68, CVX
Attack Submarines	SSN774, SSN688, SSN21
Amphibious Assault Ships	LHA, LHD, LHX
Landing Dock Ships	LSD36, LSD41
Amphibious Transport Ships	LPD4, LPD17
Fighter Aircraft	JSFN, F18EF, F18AB, F18CD, F14

Table 1 CIPA modeled Mission Areas and platforms.

Table 1 represents a prototypical subset of mission areas and associated ship classes and aircraft types. A typical mission area requirement might be to maintain at least 89 combatant destroyers (FFG, DDG, DD, or DD21) in the US Navy fleet.

SCN Mission Areas	**Ship Classes**
Destroyers	FFG, DDG, DDGX, DD, DD21
Cruisers	CG, CG21
Carriers	CVN63, CVN65, CVN68, CVX
Attack Submarines	SSN774, SSN688, SSN21
Strategic Missile Submarines	SSBN726, SSBNX
Amphibious Assault Ships	LHA, LHD, LHX
Landing Dock Ships	LSD36, LSD41, LSDX
Amphibious Transport Ships	LPD4, LPD17
Mine Countermeasure Ships	MCM1, MCMX
Mine Hunter Ships	MHC50, MHCX
Command Ships	LCC19, LCCX
Logistic AO ships	AO187, TOAX
Logistic AOE Ships	AOE1, AOE6, TADCX
Support AS Ships	AS39, ASX
Support ARS Ships	ARS50, ARSX
Support ATF Ships	ATF166, ATFX
Support TAGOS Ships	TAGOS1, TAGOS19, TAGOS23

Table 2 GENSA Modeled SCN mission areas.

Table 2 presents an extended set of SCN mission areas and associated ship classes. In addition to mission areas introduced by GENSA, those in CIPA are redefined and extended to include new ship classes such as DDGX, CG21, and LSDX.

GENSA treats a few ship classes as a fixed exogenous expense because they are few in number, diminish in the near term (before FY10), and do not have corresponding future programs. These ship classes, LST-1179, MCS-12, AGF-11, AGF-3, AE-26, AFS-1, and AFS-8, are included in MPN cost calculations because they appear in EPA/TOA.

APN Mission Areas	Aircraft Types
Fighter Aircraft	JSFN, JSFMC, F18EF, F18AB, F18CD, F14, AV8B
Attack Aircraft	EA6B, F18G
ASW Aircraft Group 1	S3B, CSAASW
ASW Aircraft Group 2	P3C, MMA
Early Warning Aircraft	E2C, E2X
Transport Aircraft	C2AB, C2X
Utility Aircraft	C12, UCX
Training Aircraft Group 1	T44, METX
Training Aircraft Group 2	T45, JTTX
Training Aircraft Group 3	T34, JPATS
Rotary Wing Group 1	TH57, THX
Rotary Wing Group 2	MV22, CH46E, CH53D

Table 3 GENSA Modeled APN mission areas.

GENSA has an extended set of APN mission areas and aircraft types. The CIPA fighter aircraft mission area has been generalized in GENSA to include the Marine Corps JSF and AV8B aircraft types.

GENSA treats some aircraft types as a fixed exogenous expense for one or more of the following reasons: the type is few in number, the number is not expected to change over time or diminishes in the near term (before FY10), the inventory level is not known precisely, the aircraft is difficult to associate with a specific mission category, or there is no corresponding future program for planning purposes. Such types include F-5EF, EA-6, EP-3, R/NP-3, DC-9, C-40, C-20, C130, P-3AB, T-2, T-38, T-39, TC-18, AH-1W, UH/HH-1N/Y, O/TH-6, VRH (CH-60), SH/VH/UH-3, and JRA. These aircraft types are included in MPN cost calculations because they appear in EPA/TOA.

B. MANPOWER AND MPN CALCULATIONS IN GENSA

GENSA calculates the officer and enlisted manpower costs associated with ships and aircraft for its recommended force structures by incorporating VAMOSC data [Naval Center for Cost Analysis 2000]. MPN is not considered by CIPA.

Table 4 shows how VAMOSC ship data Cost Element Structures (CES) are arranged to estimate MPN and MPN costs for a single DDG class surface ship. Future ship classes and aircraft types are assumed to mimic their most similar present correspondents. All costs are in FY00$.

Years	Average Officer Manpower Cost per Ship	Average Enlisted Manpower Cost per Ship	Average Enlisted Complement per Ship	Average Officer Complement per Ship	Number Of Ships
FY92	1,483,373	9,150,583	306	23	1
FY93	1,417,678	9,077,393	302	22	1
FY94	1,435,618	8,944,281	310	22	2
FY95	1,467,964	9,034,536	310	24	6
FY96	1,448,718	8,825,840	291	24	11
FY97	1,411,270	8,706,772	281	23	16
FY98	1,953,801	10,512,777	269	23	21
FY99	1,993,189	10,328,918	273	25	24
Averages	**1,576,451**	**9,322,638**	**293**	**23**	

Table 4 MPN costs for the DDG surface combatant class.

MPN costs are estimated by averaging the yearly cost of officer and enlisted manpower complements. Data is taken from VAMOSC ship data. GENSA uses these class averages for DDG and for its future variant DDGX.

Because the Officer Manpower Navy and Enlisted Manpower Navy cost elements are not available for all aircraft types in VAMOSC aircraft data [Andrews 2000], MPN cost is estimated for similar aircraft types.

Table 5 shows the average military aircraft personnel costs estimates.

Years	Average Military Personnel Cost per Aircraft ($)	Aircraft Inventory
FY88	321,042	418
FY89	286,943	471
FY90	399,373	527
FY91	394,704	560
FY92	256,459	631
FY93	357,532	718
FY94	336,494	683
FY95	337,535	747
FY96	327,313	767
FY97	349,838	718
FY98	334,845	719
Average	**336,552.545**	

Table 5 Military personnel costs (MPN) for FA-18 aircraft.

GENSA uses the average (MPN) cost for all variants of FA-18 type aircraft (FA-18AB, FA-18CD, FA-18EF) as well as for Navy and Marine variants of the Joint Strike Fighter.

C. OPERATING AND MAINTENANCE COST (OMN) IN GENSA

GENSA estimates Operating and Maintenance (OMN) cost for each ship class and aircraft type from VAMOSC data. Table 6 shows how four major VAMOSC cost elements contribute to the OMN cost for DDG surface combatants.

Years	Average Direct Unit Cost per Ship	Average Direct Intermediate Maintenance Cost per Ship	Average Direct Depot Maintenance And Modernization Cost per Ship	Average Indirect Operating And Support Cost per Ship	Average Total OMN Cost per Ship	Number Of Ships
FY92	17,806,868	86,344	167,359	828,003	18,888,574	1
FY93	17,206,525	168,450	638,282	845,636	18,858,893	1
FY94	17,758,009	235,280	2,174,806	1,097,663	21,265,758	2
FY95	16,803,140	176,341	4,219,464	1,128,380	22,327,325	6
FY96	17,004,193	285,278	3,172,637	961,458	21,423,566	11
FY97	15,363,910	397,082	7,518,799	975,503	24,255,294	16
FY98	18,302,035	449,238	12,199,727	904,813	31,855,813	21
FY99	19,791,502	345,044	4,061,524	875,118	25,073,188	24
Average					**22,993,551**	

Table 6 DDG average OMN cost.

GENSA estimates the OMN cost from VAMOSC for DDG surface combatants as shown (FY00$). The same cost is used for the future variant class DDGX.

Table 7 displays the six major cost elements of VAMOSC aircraft data that incorporate average total OMN cost of a FA-18 aircraft type. All costs are in FY00$.

Years	Average Organizational Cost per Aircraft	Average Intermediate Cost per Aircraft	Average Depot Support Cost per Aircraft	Average Training Support Cost per Aircraft	Average Recurring Investment Cost per Aircraft	Average Other Functions Cost per Aircraft	Average Total OMN Cost per Aircraft	Total Aircraft Number
FY88	669,762	183,796	84,979	206,209	2,522	13,776	1,161,044	418
FY89	655,453	127,324	73,867	194,142	10,882	16,797	1,078,465	471
FY90	780,694	200,651	101,307	205,470	2,087	14,407	1,304,616	527
FY91	889,388	184,966	68,610	220,446	0	5,437	1,368,847	560
FY92	753,226	88,422	99,613	193,921	17,726	12,742	1,165,650	631
FY93	933,605	121,658	88,179	217,625	46,604	16,131	1,423,802	718
FY94	995,464	120,944	141,179	228,343	19,329	12,952	1,518,211	683
FY95	1,145,719	120,205	100,060	281,657	83,739	15,954	1,747,334	747
FY96	1,023,638	172,905	176,105	255,185	128,828	15,157	1,771,818	767
FY97	1,011,847	120,921	91,886	251,569	204,824	13,214	1,694,261	718
FY98	1,042,231	113,530	79,973	261,279	218,672	13,810	1,729,495	719
Average							1,451,231.18	

Table 7 FA-18 aircraft type OMN averages.

GENSA estimates OMN cost from VAMOSC for the FA-18 aircraft type. GENSA uses this estimate for all FA-18 variants (FA-18AB/CD/EF) and for Navy and Marine versions of Joint Strike Fighter.

IV. MODEL

A. INTRODUCTION

As in CIPA, GENSA makes uses of binary and continuous decision variables for procurement planning. The number of ships procured in a given year at a quantity level is defined as a binary variable. Advanced payments for a ship before its delivery are also governed by a binary variable. In aircraft procurement, the increment level in a given year is determined by a binary variable. By this approach aircraft procurement is made semi-continuous between increment levels. The numbers of retiring ships or aircraft in a given year are represented by continuous variables. For a given year, the number of ships in a class, number of aircraft in a type, and mission inventory levels are defined by continuous variables.

B. FORMULATION

Indices

Platform

a	aircraft type	{JSFN, F18EF,...}
s	ship class	{DDG, DD21, CVX, SSN-774,...}

Mission

m	mission area	{combatant, carrier, fighter...}
a_m	subset of aircraft types that perform mission m For example, a_{fighter} = {JSFN, JSFMC, F18EF, F18CD, F18AB, F14, AV8B}	
s_m	subset of ship classes that perform mission m For example, s_{carrier} = {CVX, CVN63, CVN65, CVN68}	

Production

i	cost increment Identifies segment of piecewise linear, non-convex cost functions	{1,2,3}
p	production facility	{Bath, Ingals, News, Eboat, ...}
p_s	subset of facilities that produce ship class s For example, P_{DDG} = {Bath, Ingals}	
q	number of ships	{0,1,2,3,4}

Budget

c	category of money	{SCN, OMN, APN}

Temporal

y, y'	Fiscal Year	{FY06, FY07, ..., FY30}

index data and dependencies

constyrs_{sp}	years to build a class s ship at facility p (starting in y and delivered at the start of year $d = y + \text{constyrs}_{sp}$)

Data (Data units are shown in parentheses)

SCN related parameters

bShipInv_s	initial inventory of class s ships (ship)
frac	historical fraction of total SCN cost for ship outfitting
otherScn_y	a fixed SCN cost in year y (FY00$M)
oldShips_{sy}	number of class s ships to retire by the end of year y (ship)
omnCostShip_s	OMN cost per class s ship in year y (FY00$M per ship)
maxRetShips_{sy}	maximum number of ships of class s to retire in year y
$\text{scost}_{qsyy'}$	SCN cost in year y if q units of ship s start production in year y' (FY00$M)
upShip_{sy}	maximum number of class s ships in inventory (ship)

APN related parameters

acost_{aiy}	increment i procurement cost per type a aircraft for year y delivery (FY00$M)
apn5	historical fraction of total APN categories 1 thru 4 required for categories 5 thru 7
b_{aiy}	increment i fixed procurement cost (intercept) for delivery in year y of aircraft type a (FY00$M)
bAirInv_a	initial inventory of type a aircraft (aircraft)
$\overline{\text{inc}}_{aiy}$, $\underline{\text{inc}}_{aiy}$	increment i upper and lower bound for the number of type a aircraft procured for delivery in year y (aircraft)
oldAir_{ay}	number aircraft of type a to retire by the start of year y (aircraft)

omnCostAir_{a}	OMN cost per type a aircraft (FY00\$M)
maxRetAir_{ay}	maximum number of aircraft type a to retire in year y
upAir_{ay}	maximum number of aircraft type a in inventory (aircraft)

Mission

bInv_{m}	initial inventory available to perform mission m (platform)
mreq_{m}	number of platforms required for mission m (platform)

Penalties

mreqpen_{m}	penalty per unit violation of requirement mreq_{m} (FY00\$M per platform)
$\overline{\text{pcpen}}_{py}$, $\underline{\text{pcpen}}_{py}$	penalty per unit violation of maximum and minimum production capacity for facility p in year y (FY00\$M per worker)
$\overline{\text{toapen}}_{y}$, $\underline{\text{toapen}}_{y}$	penalty per unit violation of TOA in year y (FY00\$M per FY00\$M)

Budget

otherCost_{cy}	fixed category c cost in year y for platforms not considered (FY00\$M)
$\overline{\text{toa}}_{y}$, $\underline{\text{toa}}_{y}$	TOA budget band for year y (FY00\$M)

Production

$\text{workers}_{pqsyy'}$	workers required at facility p in year y to build q ships of class s to be delivered in year y' (worker)
$\overline{\text{pcap}}_{py}$, $\underline{\text{pcap}}_{py}$	maximum and minimum production capacities for facility p in year y (worker)

Decision Variables (units are shown in parentheses)

AMT_{qsy}	one if q class s ships start production in year y, and zero otherwise
AP_{aiy}	one if aircraft a is procured in cost increment i for delivery at the start of year y, and zero otherwise

APROC_{aiy}	number of type a aircraft to procure in cost increment i for delivery at the start of year y (aircraft)
ARET_{ay}	number of type a aircraft to retire at the start of year y (aircraft)
BUDGET_{cy}	amount of money c to budget for year y (FY00$M)
INV_{my}	inventory available for mission m at the start of year y (platform)
SPROC_{pqsy}	one if facility p is to deliver q class s ships at the start of year y, and zero otherwise
SRET_{sy}	number of class s ships to retire at the start of year y (ship)
TOTAIR_{ay}	number of type a aircraft operational at the start of year y
TOTSHIP_{sy}	number of class s ships operational at the start of year y

Formulation

MINIMIZE: Penalties for $\overline{\text{toapen}}_y$, $\underline{\text{toapen}}_y$, $\overline{\text{pcpen}}_{py}$, $\underline{\text{pcpen}}_{py}$, and mreqpen_m.

SUBJECT TO:

Ship

$$\sum_{p \in P_s, q} q\ \text{SPROC}_{pqs, y+constyrs_{sp}} = \sum_q q\ \text{AMT}_{qsy} \qquad \forall s, y \quad (1)$$

$$\sum_q \text{AMT}_{qsy} \le 1 \qquad \forall s, y \quad (2)$$

$$\sum_q \text{SPROC}_{pqsy} \le 1 \qquad \forall p, s, y \quad (3)$$

$$\sum_{p \in P_s, q, y' \le y} q\ \text{SPROC}_{pqsy'} - \sum_{y' \le y} \text{SRET}_{sy'} + \text{bShipInv}_s = \text{TOTSHIP}_{sy} \qquad \forall s, y \quad (4)$$

$$\text{TOTSHIP}_{sy} \le \text{upShip}_{sy} \qquad \forall s, y \quad (5)$$

Aircraft

$$\underline{\text{inc}}_{aiy}\ \text{AP}_{aiy} \le \text{APROC}_{aiy} \le \overline{\text{inc}}_{aiy}\ \text{AP}_{aiy} \qquad \forall a,i,y \quad (6)$$

$$\sum_{i} \text{AP}_{aiy} \le 1 \qquad \forall a,y \quad (7)$$

$$\sum_{i,y' \le y} \text{APROC}_{aiy'} - \sum_{y' \le y} \text{ARET}_{ay'} + \text{bAirInv}_{a} = \text{TOTAIR}_{ay} \qquad \forall a,y \quad (8)$$

$$\text{TOTAIR}_{ay} \le \text{upAir}_{ay} \qquad \forall a,y \quad (9)$$

Retirement

$$\sum_{y' \le y} \text{SRET}_{sy'} \ge \text{oldShips}_{sy} \qquad \forall s,y \quad (10)$$

$$\text{SRET}_{sy} \le \text{maxShipRet}_{sy} \qquad \forall s,y \quad (11)$$

$$\sum_{y' \le y} \text{ARET}_{ay'} \ge \text{oldAir}_{ay} \qquad \forall a,y \quad (12)$$

$$\text{ARET}_{ay} \le \text{maxRetAir}_{ay} \qquad \forall a,y \quad (13)$$

Mission Inventory

$$\text{bInv}_{m} + \text{INV}_{m,\,y\text{-}1} + \sum_{p,q,s \in s_m} q\ \text{SPROC}_{pqsy} - \sum_{s \in s_m} \text{SRET}_{sy}$$

$$+ \sum_{a \in a_m, i} \text{APROC}_{aiy} - \sum_{a \in a_m} \text{ARET}_{ay} = \text{INV}_{my} \qquad \forall m,y \quad (14)$$

$$\text{INV}_{my} \ge \text{mreq}_{m} \qquad \forall m,y \quad (15)$$

Budget

$$\text{otherScn}_{y} + (1 + \text{frac})\left(\text{otherCost}_{\text{SCN},y} + \sum_{q,s,y'} \text{scost}_{qsyy'} \text{AMT}_{qsy'} \right)$$

$$= \text{BUDGET}_{\text{SCN},y} \qquad \forall y \quad (16)$$

$$(1+\text{apn5})\left(\text{otherCost}_{\text{APN},y}+\sum_{a,i}\text{acost}_{ai,y+2}\text{APROC}_{ai,y+2}\ +\text{b}_{ai,y+2}\text{AP}_{ai,y+2}\right)$$

$$=\text{BUDGET}_{\text{APN},y} \qquad \forall y \qquad (17)$$

$$\text{otherCos}_{\text{OMN},y}+\sum_{s}\left(\text{omnCostShip}_{s}\text{TOTSHIP}_{sy}\ \right)+\sum_{a}\left(\text{omnCostAir}_{a}\text{TOTAIR}_{ay}\right)$$

$$=\text{BUDGET}_{\text{OMN},y} \qquad \forall y \qquad (18)$$

$$\sum_{y'\le y}\underline{\text{toa}}_{y}\ \overset{\bullet}{\le}\ \sum_{c,y'\le y}\text{BUDGET}_{cy}\ \overset{\bullet}{\le}\ \sum_{y'\le y}\overline{\text{toa}}_{y} \qquad \forall y \qquad (19)$$

Industrial

$$\sum_{q,s,y'}\text{workers}_{pqsyy'}\ \text{SPROC}_{pqsy'}\ \overset{\bullet}{\le}\ \overline{\text{pcap}}_{py} \qquad \forall p,y \quad (20)$$

$$\sum_{q,s,y'}\text{workers}_{pqsyy'}\ \text{SPROC}_{pqsy'}\ \overset{\bullet}{\ge}\ \underline{\text{pcap}}_{py} \qquad \forall p,y \quad (21)$$

Non-negativity

$\text{ARET}_{ay}\ge 0\ \forall a,y;\ \ \text{SRET}_{sy}\ge 0\,\forall s,y;\ \ \text{BUDGET}_{cy}\ge 0\,\forall c,y;\ \ \text{INV}_{my}\ \ge 0\ \forall m,y;$
$\text{TOTSHIP}_{sy}\ge 0\ \forall s,y;\ \ \text{TOTAIR}_{ay}\ge 0\ \forall a,y;\ \ \text{APROC}_{aiy}\ge 0\ \forall a,i,y$

Binary Variables

$\text{SPROC}_{pqsy}\in\ \{0,1\}\ \forall p,q,s,y;\ \ \ \text{AMT}_{qsy}\ \in\ \{0,1\}\ \forall q,s,y;\ \ \ \text{AP}_{aiy}\ \in\ \{0,1\}\ \forall a,i,y$

Constraints (1) and (2) determine the number of ships that start construction in year y. For a specific facility, constraints (3) ensure that at most one quantity of ships is procured for delivery in a given year. Constraints (4) calculate the yearly total number of ships within each class based on procurements, retirements, and initial inventory levels. Yearly, upper bound (5) ensures the total number of ships in a class does not exceed an upper limit. Constraints (6) and (7) constitute a piecewise linear, non-convex approximation of aircraft procurement cost as a function of volume procured.

Constraints (8) calculate the yearly total number of aircraft based on procurements, retirements, and initial inventory levels. Upper bound (9) ensures the yearly total number of each aircraft type does not exceed an upper limit. Constraints (10) and (12) respectively ensure that enough ships and aircraft are retired each year to meet cumulative retirement goals, which upper bounds (11) and (13) limit. Constraints (14) calculate the inventory of ships or aircraft available to perform a mission; constraints (15) suggest that sufficient ships and aircraft should be available to satisfy mission requirements in a given year or a penalty is charged. Constraints (16) through (18) respectively calculate the total amount of SCN, APN, and OMN money spent each year. Constraints (19) ensure TOA either remains within a cumulative yearly budget band or an appropriate penalty is charged. Constraints (20) and (21) suggest that scheduled work be within the capabilities of each facility or a penalty is charged.

In GENSA we preserve the elastic constraints, elastic variables and the penalty function as in CIPA [Field, 1999].

C. MPN AND MPN COST CALCULATIONS IN GENSA

Indices

r	personnel type	{officer, enlisted}

Data

(Data units are shown in parenthesis)

crewShip_{rs}	Number of personnel r Navy for ship class s
crewCostShip_{rs}	Cost of personnel type r for ship class s (FY00\$M)
crewAir_{ar}	Number of personnel r Navy for aircraft type a
crewCostAir_{a}	Military personnel (officer and enlisted) cost for aircraft type a (FY00\$M)

Calculations

$$\sum_{r,s} \text{crewShip}_{rs}\ \text{TOTSHIP}_{sy} \qquad \forall y \qquad (22)$$

$$\sum_{r,s} \text{crewCostShip}_{rs}\ \text{TOTSHIP}_{sy} \qquad \forall y \qquad (23)$$

$$\sum_{a,s} \text{crewAir}_{ar}\ \text{TOTAIR}_{ay} \qquad \forall y \qquad (24)$$

$$\sum_{a,r} \text{crewCostAir}_{ar}\ \text{TOTAIR}_{ay} \qquad \forall y \qquad (25)$$

In a given year, equation (22) calculates yearly Navy MPN levels of operational ships and equation (23) displays the financial impact of MPN levels. Equation (24) calculates the MPN levels required for operational aircraft in a specific year and equation (25) calculates military personnel cost for operational aircraft.

V. IMPLEMENTATION AND ANALYSIS

A. MODEL IMPLEMENTATION

GENSA is implemented in the General Algebraic Modeling System (GAMS) [Brooke et al 1998] with the Version 7.0 CPLEX solver [ILOG 2000]. GENSA is implemented over a 30-year horizon with 29 mission areas, 45 ship classes, 30 aircraft types, 13 shipbuilding facilities, and three categories of money. The model has approximately 32,350 equations, 67,851 continuous variables, and 5,200 binary variables.

During the planning horizon, FY01-05 are fixed as in EPA/TOA. GENSA provides procurement and retirement scheduling between FY06 and FY30. N81 considers 25 years (FY01 to FY25) to be an appropriate timeframe for analysis. GENSA includes years FY26 to FY30 to moderate end effects.

Using a relative integer termination tolerance of five percent, GENSA usually runs in less than one minute on a personnel computer with 1 gigabyte of random access memory and a 500 megahertz Intel Pentium processor. An unusually tightly constrainted scenario takes about ten minutes.

B. DATA

1. Ship Procurement Cost

In GENSA, procurement cost functions for present ship classes, aircraft types, and their future variants are updated in accordance with EPA/TOA RAD7 calculations [SPA 2000].

SCN spending for other than the procurement cost of platforms is categorized as a post delivery cost, first destination transfer cost, Landing Craft Air Cushion (LCAC) and Service Craft procurement cost, taken directly from the EPA/TOA RAD7 scenario Table 8). Outfitting cost of procured platforms is approximated by a historical 3.37% of yearly SCN money.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Delivery Cost ($M)	0	0	0	0	0	0	0	0	0	0	0	0	0
Transfer Cost($M)	0	0	0	0	0	0	0	0	0	0	0	0	0
LCAC($M)	0	35	0	35	0	35	0	35	0	35	0	35	0
otherCost(M$)	0	0	0	0	0	0	0	0	0	0	0	0	0

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Delivery Cost ($M)	0	0	0	0	0	0	0	0	0	0	0	0
Transfer Cost($M)	0	0	0	0	0	0	0	0	0	0	0	0
LCAC($M)	35	0	0	0	0	0	0	0	0	0	0	0
otherCost(M$)	0	0	0	0	0	0	0	0	0	0	0	0

Table 8 Other SCN money.

Other SCN money spent on other than the procurement of new platforms. For the EPA/TOA RAD7 scenario, post delivery cost and first destination cost are not considered and LCAC are procured once every two years until FY19. The yearly "otherCost" is zero because we include all ship classes in GENSA.

In GENSA we use piecewise linear cost approximations for ship and submarine procurements to mimic EPA/TOA's complex cost estimation functions. We keep the error margin (the difference between the piecewise approximation and EPA/TOA cost, dividing by EPA /TOA cost) lower than one percent.

Table 9 displays the piecewise linear SCN procurement cost approximations.

Ship Class	Purchase Quantity	One Year Advanced Procurement (M$)	Two Year Advanced Procurement (M$)	Procurement Cost Function(M$)	
				Intercept	Slope
DDG(X)	1	0	0	1,191.318	0
	2,3	0	0	758.960	550.450
	4-6	0	0	1,021.650	465.080
CG-21	1	0	0	1,825.090	0
	2,3	0	0	1,171.500	832.640
	4-6	0	0	1,845.070	645.180
DD-21	1	0	0	1,822.059	0
	2,3	0	0	1,012.441	690.855
	4-6	0	0	1,621.420	517.901
CV(X)	1	0	2121 00	4,781.000	0
LH(X)	1	0	0	2,154.732	0
	2-4	0	0	1,294.911	0
LSD(X)	1	0	0	486.887	0
	2-6	0	0	383.294	0
SSBNX	1	0	1st ship: 217.545	2,993.834	0
	2,3	0	subsq: 133 635	1,619.157	0
SSN774	1	217.540	429.910	1,020.390	0
	2,3	217.540	429.910	112.023	931.624
	4-6	217.540	429.910	218.279	901.718
SSN(X)	1	212.545	429.910	1,020.390	0
	2,3	212.545	429.910	112.023	931 624
MCM(X)	1	0	0	367.755	0
	2-6	0	0	248 880	0
MHC(X)	1	0		215.470	0
	2,3	0	0	161.600	0
LCC(X)	1-6	0	0	487.296	0
TA0(X)	1	0	0	245.515	0
	2,3	0	0	110.570	151.150
	4-6	0	0	204.903	122.280
T/ADCX	1	0	0	324.547	0
	2,3	0		13.130	305.646
	4-6	0	0	45.958	296.611
AS(X)	1	0	0	751.040	0
	2,3	0	0	101.138	676.656
	4-6	0		210.930	647.007
ARS(X)	1	0	0	248.343	0
	2,3	0	0	51.927	208.568
TATF(X)	1	0	0	134.774	0
	2,3	0	0	22.658	117.478
TAGOS23	1-6	0	0	188.539	0

Table 9 Ship Procurement Cost Data.

Table 9 displays procurement cost of ships and submarines. Procurement costs are tangential piecewise linear approximations of the EPA/TOA cost functions. Advanced procurement costs are also included for CVX, SSBNX, and SSN774 class submarines.

2. Aircraft Procurement Cost

Fixed APN cost for aircraft is taken from EPA/TOA. These data include procurement cost for the aircraft not modeled in GENSA and also total cost of APN categories five thorough seven (money budgeted for spares, repair parts, support equipment and facilities). APN5-7 is modeled as a historic fraction of APN1-4, the actual procurement cost for new platforms.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Other APN Cost ($M)	496.119	485.942	431.767	251.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	283.010

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other APN Cost ($M)	559.574	828.926	1,090.670	1,076.590	1,063.780	1,052.040	1,041.220	773.836	767.653	508.151	504.979	501.951

Table 10 Fixed APN Cost.

Fixed APN cost is taken from EPA/TOA. The data represent the total of APN5-7 money and unmodeled aircraft.

The procurement cost data for GENSA aircraft are piecewise linear approximations of the non-convex aircraft cost functions in EPA/TOA. The cost difference is less than one percent.

For there major aircraft types, Table 11 displays the purchase quantities (three increment levels) and associated procurement costs as piecewise linear approximations.

Aircraft	Purchase Quantity	Procurement Cost Function ($M)	
		Intercept	Slope
F/A-18EF	24-30	355.177	48.428
	30-40	491.375	44.011
	40-55	683.763	39.323
JSF USN	24-30	99.349	46.290
	30-40	155.394	44.457
	40-55	258.386	41.926
JSF USMC	24-30	976.600	70.376
	30-40	1,196.064	63.252
	40-55	1,492.965	56.018

Table 11 Procurement cost for major aircraft types in GENSA. Procurement costs are piecewise linear continuous approximations of the associated EPA/TOA cost functions.

Table 12 displays the piecewise linear approximations of procurement costs for other aircraft types.

Aircraft	Procurement Quantity	Pocurement Cost Function ($M)	
		Intercept	Slope
F-18G	6-12	25.335	69.502
CSA ASW	4-12	414.110	100.390
MMA	12 -24	29.666	141.564
CSA AEW	4-8	596.634	124.107
CSA COD	1-6	17.050	51.420
UC(X)	12-24	120.200	9.385
METX	12-24	120.200	9.385
JTTX	6-12	139.151	23.125
JPATS	12-24	22.460	2.855
THX	12-24	15.285	7.185
MV-22A/B	12-24	222.36	43.79
MV-22A/B	24-36	345.14	38.58

Table 12 Aircraft Procurement Cost.
Cost of aircraft procured in various feasible ranges as modeled in GENSA. Procurement costs are piecewise linear continuous approximations of the associated EPA/TOA cost functions.

3. Ship OMN Cost

Ship OMN cost data is the class average over the last 10 years (or over those years available) of VAMOSC ship data. OMN fixed costs for platforms not modeled in GENSA are allocated to the fiscal years as the platforms appear in EPA/TOA model. OMN fixed costs are displayed in Table 13. The OMN cost for future platforms is approximated by the most similar present system's OMN cost.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Other OMN Cost ($M)	361.564	438.435	146.200	34.946	34.946	0	0	0	0	0	0	0	0

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other OMN Cost ($M)	0	0	0	0	0	0	0	0	0	0	0	0

Table 13 Fixed OMN cost for platforms not included in GENSA model.

OMN costs for ship classes modeled in GENSA are summarized in Table 14.

Ships	FFG-7	DDG-51	DDGX	CG-47	CG-21	DD-963	DD-21	CV-63/67	CVN-65
Average OMN Cost per ship(M$)	17.299	22.994	22.994	29.571	29.571	38.175	38.175	174.672	253.741

Ships	CVN-68-77	CVX	LHD-1	LHA-1	LH(X)	LSD-41/49	LSD-36	LSD(X)	LPD-17
Average OMN Cost per ship(M$)	199.902	199.902	67.202	83.460	67.202	22.744	22.567	22.744	29.685

Ships	LPD-4	SSBN-726	SSBNX	SSN-21	SSN774	SSN(X)	SSN-688	MCM-1	MCM(X)
Average OMN Cost per ship(M$)	29.685	56.968	56.968	8.216	23.629	23.629	23.629	6.904	6.904

Ships	MHC-50	MHC(X)	LCC-19	LCC(X)	TAO-187	TAO(X)	AOE-6	AOE-1	T/ADCX
Average OMN Cost per ship(M$)	3.639	3.639	46.776	46.776	12.472	12.472	31.675	38.076	31.675

Ships	AS-39	AS(X)	ARS-50	ARS(X)	TATF-166	TATF(X)	TAGOS1-18	TAGOS-19	TAGOS-23
Average OMN Cost per ship(M$)	64.882	64.882	7.279	7.279	5.149	5.149	2.787	3.499	3.499

Table 14 OMN cost for GENSA modeled ship and submarine classes. Costs are class averages of VAMOSC ship data.

4. Aircraft OMN Cost

Aircraft OMN cost data are the type average over the last 10 years (or over those years available) of VAMOSC aircraft data. OMN costs for aircraft types not included in GENSA are imported to the model as a fixed OMN cost. Fixed OMN cost totals, displayed in Table 15, are based on EPA/TOA quantities of aircraft not modeled.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Other OMN Cost ($M)	386.626	395.233	388.952	380.386	386.805	386.620	381.518	375.974	368.960	364.886	360.733	356.100	350.801

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other OMN Cost ($M)	342.140	342.308	345.478	353.256	359.152	357.574	362.412	365.375	365.166	371.422	375.042	373.181

Table 15 Fixed OMN cost for aircraft not modeled in GENSA.

OMN data for aircraft modeled in GENSA is displayed in Table 16.

Aircraft	F18EF	JSFN	JSFMC	F14	F18CD	EA6B	AV8
Average OMN Cost per Aircraft($M)	1.451	1.451	1.451	0.995	1.451	0.863	0.306

Aircraft	F18G	P3C	MMA	S3B	CSAASW	E2C	E2X
Average OMN Cost per Aircraft($M)	1.451	0.301	0.301	0.570	0.570	0.353	0.353

Aircraft	C12	UCX	C2AB	C2X	CH46E	CH53D	MV22
Average OMN Cost per Aircraft($M)	0.306	0.306	0.088	0.088	0.558	0.503	0.558

Aircraft	TH57	THX	T34	JPATS	T44	METX	T45	JTTX
Average OMN Cost per Aircraft($M)	0.041	0.041	0.125	0.125	0.026	0.026	0.072	0.072

Table 16 OMN cost for the aircraft modeled in GENSA.

OMN cost for an aircraft type is the average VAMOSC cost. Future platforms are approximated by the most similar current type.

5. Ship MPN Data

Ship officer and enlisted MPN data is the class average over the last 10 years (or over the years available) of VAMOSC ship data. MPN levels, displayed in Table 17, are fixed for platforms not modeled in GENSA. For future platforms MPN levels are approximated by the most similar present one.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other Officer MPN	355	270	132	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Enlisted MPN	5423	3471	1919	632	632	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 17 Fixed officer and enlisted MPN data for ships not modeled in GENSA.

Officer and enlisted MPN for ship classes modeled in GENSA are summarized in Table 18.

Ships	FFG-7	DDG-51	DDGX	CG-47	CG-21	DD-963	DD-21	CV-63/67	CVN-65
Average Officer Complement per ship	17	23	23	28	28	23	23	146	175
Average Enlisted Complement per ship	192	293	293	340	340	303	303	2,751	2,917

Ships	CVN-68-77	CVX	LHD-1	LHA-1	LH(X)	LSD-41/49	LSD-36	LSD(X)	LPD-17
Average Officer Complement per ship	162	162	68	60	68	23	20	23	25
Average Enlisted Complement per ship	2,751	2,751	1,023	903	1,023	291	299	291	337

Ships	LPD-4	SSBN-726	SSBNX	SSN-21	SSN-774	SSN(X)	SSN-688	MCM-1	MCM(X)
Average Officer Complement per ship	25	31	31	14	20	20	15	7	7
Average Enlisted Complement per ship	354	299	299	126	115	115	127	74	74

Ships	MHC-50	MHC(X)	LCC-19	LCC(X)	TAO-187	TAO(X)	AOE-6	AOE-1	T/ADCX
Average Officer Complement per ship	5	5	43	43	1	1	31	29	31
Average Enlisted Complement per ship	47	47	701	701	22	22	473	551	473

Ships	AS-39	AS(X)	ARS-50	ARS(X)	TATF-166	TATF(X)	TAGOS1	TAGOS-19	TAGOS-23
Average Officer Complement per ship	59	59	8	8	0	0	0	0	0
Average Enlisted Complement per ship	1,035	1,035	94	94	5	5	12	5	20

Table 18 SCN MPN Levels.
Officer and Enlisted MPN levels on ships and submarines modeled in GENSA. Numbers of officer and enlisted on board are the class averages of the ships found in the VAMOSC ship data.

6. Aircraft MPN Data

Aircraft officer and enlisted MPN data is the type average over last 10 years (or over those years available) of VAMOSC aircraft data. For future platforms, MPN levels are approximated by the most similar present one.

MPN levels, displayed in Table 19, are fixed for aircraft types not modeled in GENSA. Table 20 displays the MPN data for aircraft modeled in GENSA.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Other Officer MPN	1,075	1,097	1,078	1,060	1,066	1,056	1,033	1,008	980	969	956	941	922
Other Enlisted MPN	951	963	943	925	926	920	910	892	846	817	806	788	776

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other Officer MPN	877	878	889	914	940	945	965	976	976	996	1,007	1,006
Other Enlisted MPN	726	711	692	694	722	733	754	770	780	804	819	818

Table 19 Total fixed officer and enlisted MPN levels for the platforms not modeled in GENSA.

Aircraft	F18EF	JSFN	JSFMC	F14	F18CD	EA6B	AV8
Number of Officer Personnel	1	1	1	2	1	4	1
Number of Enlisted Personnel	0	0	0	0	0	0	0

Aircraft	F18G	P3C	MMA	S3B	CSAASW	E2C	E2X
Number of Officer Personnel	1	5	5	2	2	2	2
Number of Enlisted Personnel	0	7	7	0	0	3	3

Aircraft	C12	UCX	C2AB	C2X	CH46E	CH53D	MV22
Number of Officer Personnel	2	2	2	2	2	2	2
Number of Enlisted Personnel	0	0	0	0	1	1	1

Aircraft	TH57	THX	T34	JPATS	T44	METX	T45	JTTX
Number of Officer Personnel	2	2	2	2	2	2	2	2
Number of Enlisted Personnel	0	0	0	0	0	0	0	0

Table 20 Officer and enlisted MPN levels for aircraft types modeled in GENSA. MPN levels for future platforms are approximated by similar present ones.

7. Ship MPN Cost

MPN costs for ships and submarines are the class average of the Officer and Enlisted complement costs taken from VAMOSC ship data. Table 21 displays the fixed MPN cost of platforms not modeled in GENSA.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Other Officer MPN Cost (M$)	28.193	31.718	9.640	3.468	3.468	0	0	0	0	0	0	0	0
Other Enlisted MPN Cost (M$)	185.540	203.630	63.800	19.538	19.500	0	0		0	0	0	0	0

Fiscal Year	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Other Officer MPN Cost (M$)	0	0	0	0	0	0	0	0	0	0	0	0
Other Enlisted MPN Cost (M$)	0	0	0	0	0	0	0		0	0	0	0

Table 21 MPN cost of Military Personnel for ships not included in GENSA.

Table 22 displays the MPN cost data for officer and enlisted on ships and submarines included in GENSA.

Ships	FFG-7	DDG-51	DDGX	CG-47	CG-21	DD-963	DD-21	CV-63/67	CVN-65
Average Officer MPN Cost per ship(M$)	1.441	1.576	1.576	2.410	2.410	1.827	1.827	11.680	14.888
Average Enlisted MPN Cost per ship(M$)	7.232	9.323	9.323	12.880	12.880	10.978	10.978	97.031	108.873

Ships	CVN-68-77	CVX	LHD-1	LHA-1	LH(X)	LSD-41/49	LSD-36	LSD(X)	LPD-17
Average Officer MPN Cost per ship(M$)	13.569	13.569	5.577	5.035	5.577	1.954	1.733	1.954	2.333
Average Enlisted MPN Cost per ship(M$)	102.464	102.464	38.855	33.418	38.855	11.063	11.660	11.063	13.232

Ships	LPD-4	SSBN-726	SSBNX	SSN-21	SSN774	SSN(X)	SSN-688	MCM-1	MCM(X)
Average Officer MPN Cost per ship(M$)	2.333	2.665	2.665	1.218	1.273	1.273	1.273	0.618	0.618
Average Enlisted MPN Cost per ship(M$)	13.232	11.519	11.519	4.872	4.764	4.764	4.764	2.768	2.768

Ships	MHC-50	MHC(X)	LCC-19	LCC(X)	TAO-187	TA0(X)	AOE-6	AOE-1	T/ADCX
Average Officer MPN Cost per ship(M$)	0.503	0.503	3.789	3.789	0.070	0.070	2.539	2.433	2.539
Average Enlisted MPN Cost per ship(M$)	1.639	1.639	26.467	26.467	0.850	0.850	17.426	21.483	17.426

Ships	AS-39	AS(X)	ARS-50	ARS(X)	TATF-166	TATF(X)	TAGOS1-	TAGOS-19	TAGOS-23
Average Officer MPN Cost per ship(M$)	4.729	4.729	0.636	0.636	0.000	0.000	0.000	0.000	0.000
Average Enlisted MPN Cost per ship(M$)	52.390	52.390	3.595	3.595	0.260	0.260	0.200	0.200	0.800

Table 22 Ship and Submarine MPN Cost.

MPN cost of officer and enlisted for the ships and submarines modeled in GENSA. For example, the average officer MPN cost of an Oliver Hazard Perry (FFG-7) class destroyer is the average over 10 years of VAMOSC ship data.

8. Aircraft MPN Cost

MPN costs for aircraft are the average over the Military personnel costs found in VAMOSC aircraft data. Table 12 displays the fixed MPN cost of aircraft not modeled in GENSA.

Fiscal Year	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	**FY16**	**FY17**	**FY18**	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	**FY29**	**FY30**
Average Military Personnel Cost ($M)	119.928	117.659	114.737	116.550	116.682	115.249	113.810	112.354	111.380	110.404	109.314	107.982	106.8	105.690	105.772	106.781	109.066	110.604	109.978	111.251	111.850	111.431	113.106	114.011	113.238

Table 23 MPN cost of Military Personnel for aircraft not included in GENSA.

Table 24 displays the average military personnel cost data for aircraft types included in GENSA.

Aircraft	F18EF	JSFN	JSFMC	F14	F18CD	EA6B	AV8	F18G	P3C	MMA	S3B	CSAASW	E2C	E2X	C12	UCX	C2AB	C2X	CH46E	CH53D	MV22	TH57	THX	T34	JPATS	T44	METX	T45	JTTX
Average Military Personnel Cost ($M)	0.337	0.337	0.337	0.243	0.337	0.290	0.072	0.337	0.049	0.049	0.135	0.135	0.097	0.097	0.073	0.073	0.029	0.029	0.150	0.172	0.150	0.015	0.015	0.049	0.049	0.008	0.008	0.012	0.012

Table 24 MPN cost of Military Personnel for aircraft included in GENSA.

Yearly average military personnel cost of a FA-18EF type aircraft is 0.887(FY00$M), based on a 10-year average from VAMOSC aircraft data. MPN costs of Joint Strike Fighter (JSF) Navy and Marine Corps variants are approximated by the same number.

9. Budget Data

A GENSA budget consists of SCN, APN, and OMN monies. The modeled budget is limited with a lower and an upper range constituting a budget band. These ranges are defined as the maximum and minimum TOA observed in EPA/TOA. For the base case the upper and lower ranges are 51,042.6 (FY00$M) and 34,684.6 (FY00$M).

10. Production Facility Data

The same set of data is preserved for production facilities modeled in CIPA [Field, 1999]. Production data for the other production facilities is approximate.

11. Retirement Data

Cumulative retirement goals for ships and aircraft types modeled in GENSA are based on EPA/TOA data. Cumulative goals allow GENSA to schedule early retirements if it is beneficial.

GENSA retirement goals by year and type appear in the Appendix. Table 18 displays an instance of cumulative retirement data.

Platforms	FY06	FY07	FY08	FY09	FY10	FY11	FY12
DD	3	6	10	10	13	13	13
F14	0	30	79	79	79	79	79

Table 25 Cumulative retirement goals for DD class destroyers and F14 aircraft. Retirement goals for DD class destroyers and F14 type aircraft taken from the EPA/TOA model. The entire inventory of DD class destroyers and F14 type aircraft must be retired by FY08 and FY11 respectively.

In order to moderate model behavior, we limit the maximum number of retiring platforms by year.

Ships	FFG-7	DDG-51	DDG(X)	CG-47	CG-21	DD-963	DD-21	CV-63/67	CVN-65
Yearly Maximum Ship Retirements	4	3	0	3	0	4	0	1	1

Ships	CVN-68-77	CV(X)	LHD-1	LHA-1	LH(X)	LSD-41/49	LSD-36	LSD(X)	LPD-17
Yearly Maximum Ship Retirements	1	0	1	2	0	2	1	0	0

Ships	LPD-4	SSBN-726	SSBN(X)	SSN-21	SSN774	SSN(X)	SSN-688	MCM-1	MCM(X)
Yearly Maximum Ship Retirements	2	1	0	0	0	0	3	2	0

Ships	MHC-50	MHC(X)	LCC-19	LCC(X)	TAO-187	TA0(X)	AOE-6	AOE-1	T/ADC(X)
Yearly Maximum Ship Retirements	1	0	1	0	2	0	0	1	0

Ships	AS-39	AS(X)	ARS-50	ARS(X)	TATF-166	TATF(X)	TAGOS-1	TAGOS-19	TAGOS-23
Yearly Maximum Ship Retirements	2	0	2	0	3	0	1	1	0

Table 26 Yearly Maximum Ship Retirement.

Maximum ship retirement data provides smoothness and flexibility to GENSA. For Ticonderoga class cruisers, the maximum number of ships that can be retired at once is limited to three. Because no retirement is expected for new ship classes, these values are set to zero.

12. Mission Inventory Data

Mission inventory levels for ship classes and aircraft types modeled in GENSA are either taken directory or interpreted from EPA/TOA with advice by Kelly [2000b]. Inventory requirements for SCN and APN missions are listed in Table 27.

SCN Mission Areas	Inventory Levels (ships)
Destroyers	89
Cruisers	27
Carriers	12
Attack Submarines	50
Strategic Missile Submarines	14
Amphibious Assault Ships	12
Landing Dock Ships	12
Amphibious Transport Ships	12
Mine Countermeasure Ships	14
Mine Hunter Ships	1
Command Ships	4
Logistic AO ships	13
Logistic AOE Ships	16
Support AS Ships	2
Support ARS Ships	4
Support ATF Ships	7
Support TAGOS Ships	8

APN Mission Areas	Mission Inventory (aircraft)
Fighter Aircraft	1,200
Attack Aircraft	125
ASW Aircraft Group 1	100
ASW Aircraft Group 2	200
Early Warning Aircraft	60
Transport Aircraft	30
Utility Aircraft	80
Training Aircraft Group 1	54
Training Aircraft Group 2	110
Training Aircraft Group 3	270
Rotary Wing Group 1	120
Rotary Wing Group 2	300

Table 27 SCN and APN mission areas and required number of mission platforms.

The US Navy plans to maintain a surface fleet of 89 destroyers, 27 cruisers, and 12 aircraft carriers for the next 30 years.

C. COMPUTATIONAL RESULTS

1. Base Case

A base case is used as a reference for an excursion made to test sensitivity of results to a budget cut. In the base case, all mission requirements are satisfied over the planning horizon for SCN mission inventories (e.g., Figures 1, 2, and 3).

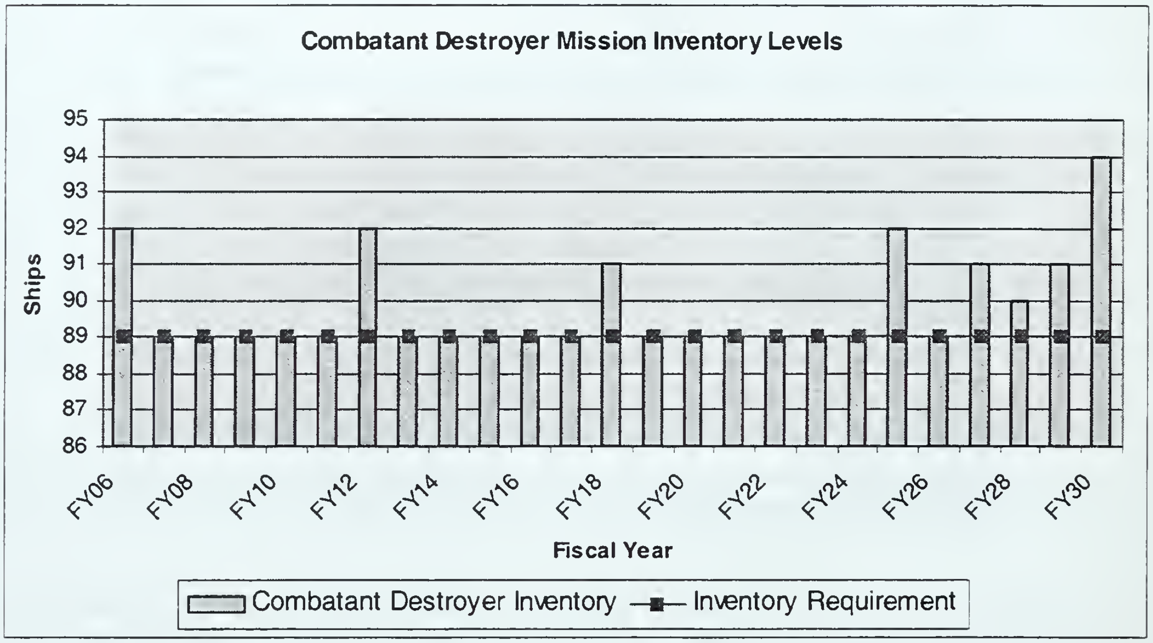

Figure 1 Base Case Combatant Destroyer Mission Inventory.

There is no combatant destroyer mission deficiency in any year, but this requirement is exceeded in FY06, 12, 18, 25, 27, 28, 29, 30. The excesses in FY06 and FY12 are in anticipation of pending retirements. The excesses in FY27 and beyond are an end effect beyond the end of N81's planning horizon.

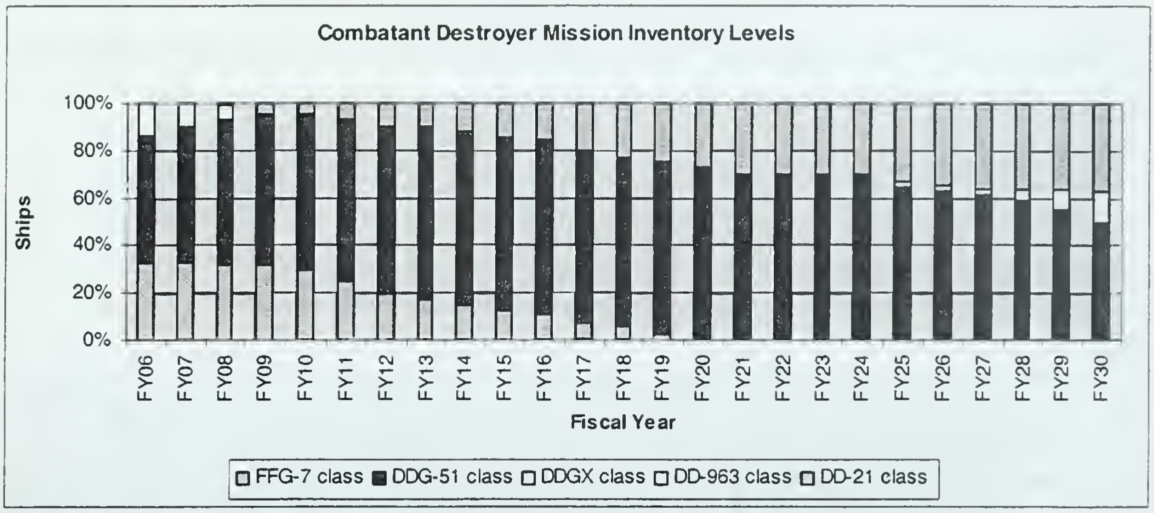

Figure 2 Base Case Combatant Destroyer Mission Totals.

The number of DDG-51 class ships reaches 65 in FY13 and stays at this level for seven years. The DD-21 class reaches 35 at the end of the planning horizon.

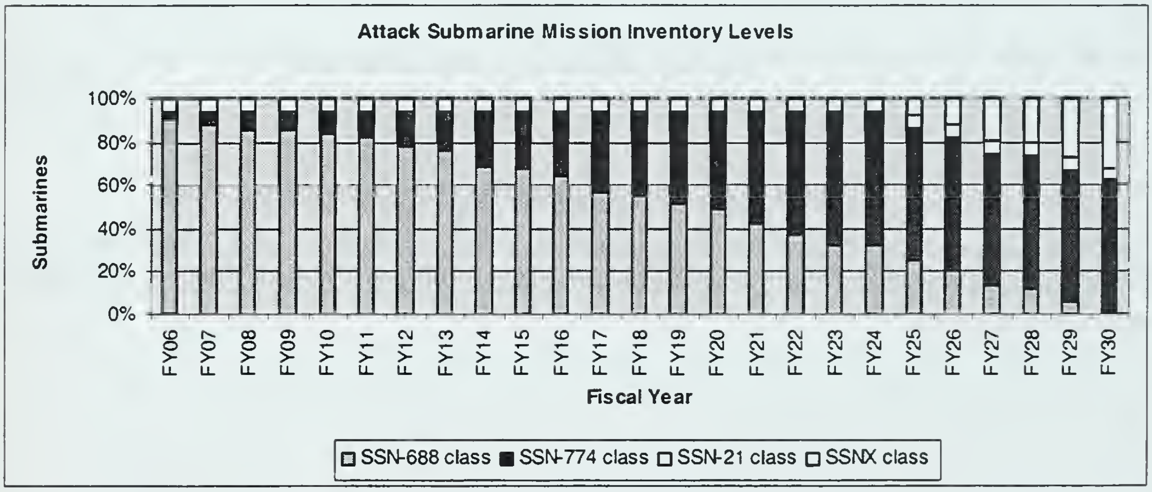

Figure 3 Base Case Attack Submarine Mission Inventory.

Base case submarine classes forming the attack submarine mission inventory. Mission requirements are maintained as Los Angeles class attack submarines (SSN-688) are replaced by Virginia class attack submaines (SSN774) and SSNX after FY25.

Some APN mission areas are not satisfied for this base case. The most serious shortage is the Fighter Mission inventory with deficiencies in the first four planning years (Figures 4 and 5).

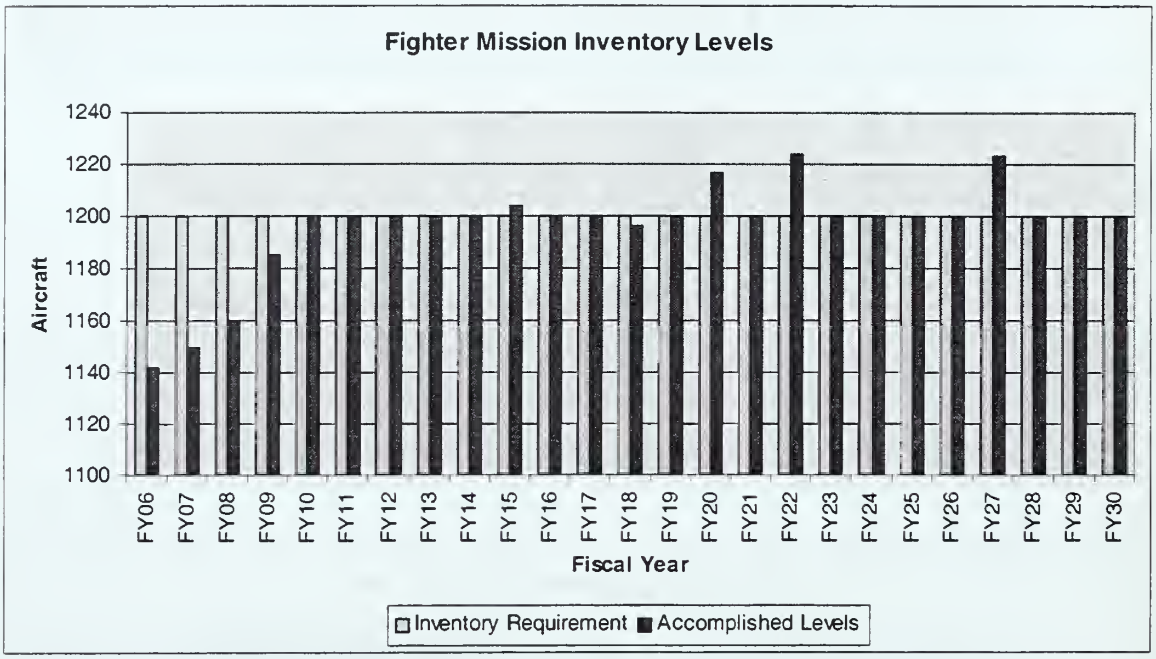

Figure 4 Base Case Fighter Mission Inventory Levels.

GENSA cannot overcome relatively significant deficits in fighter mission requirements in FY06 through FY10. As the JSF inventory increases (Figure 5), the mission requirements are eventually met.

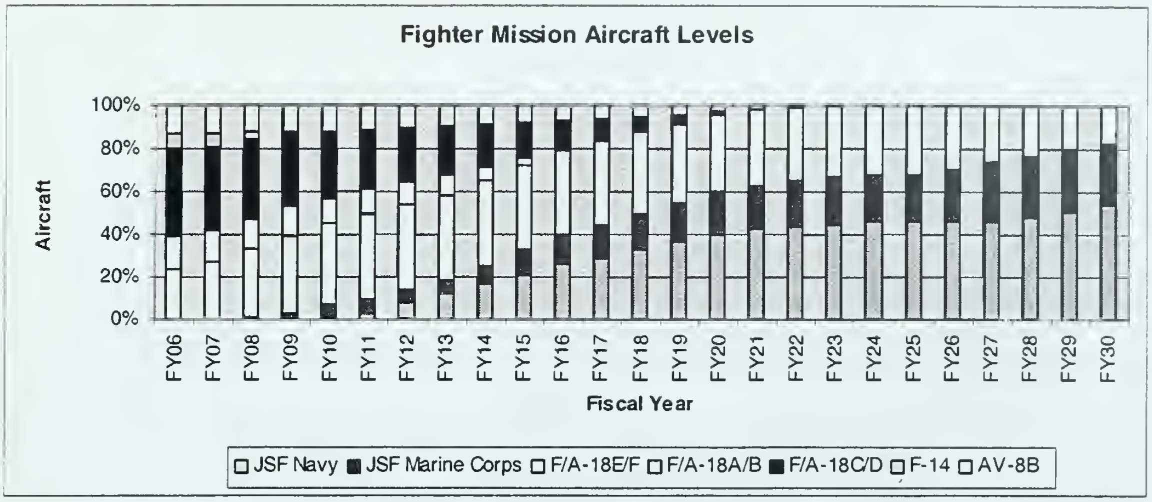

Figure 5 Base Case Fighter Mission Aircraft Levels.

Retiring F-14, AV-8B, F-18AB/CD are replaced by F-18EF and JSF. After FY20, the US Navy will operate only two aircraft types to satisfy its fighter mission.

Officer and enlisted MPN calculations based on the base case force structure are displayed below. Figures 6 and 7 shows the MPN impact of the base case force structure planning.

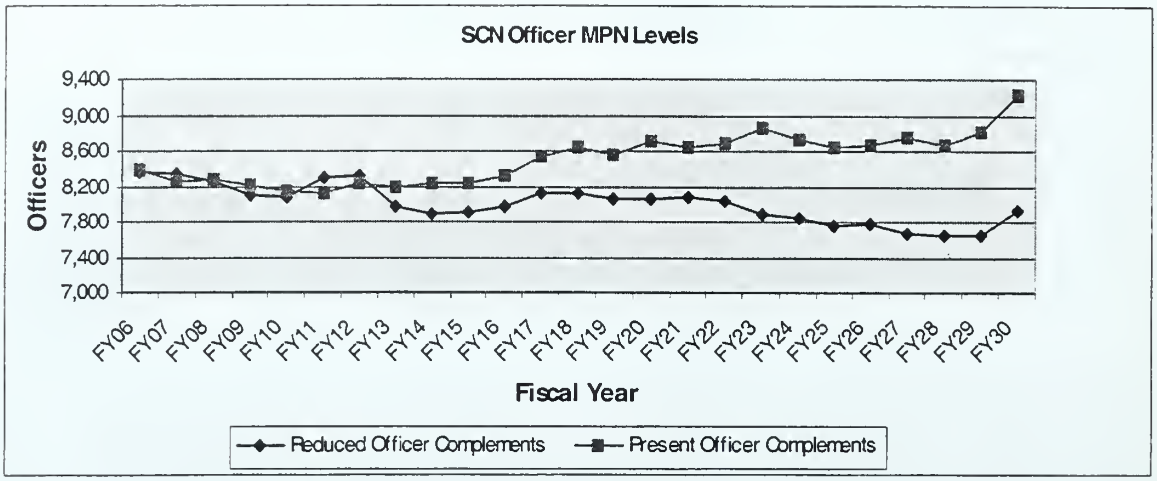

Figure 6 Base Case SCN Officer MPN Levels.

Officer SCN manpower levels for the base case force structure under two different assumptions about manning on future ship classes. When future ships have the same complement levels as the closest present ship class, there is an upward trend in officer levels over the planning horizon. The increasing levels after FY18 are primarily due to procurement of DD-21 class destroyers, SSN-774 class attack submarines, and a CVX class aircraft carrier. When assuming future ships classes will have a 25% reduction in the officer complement compared to their closest present ship class, there is a downward trend.

Enlisted MPN levels for two different cases are displayed below.

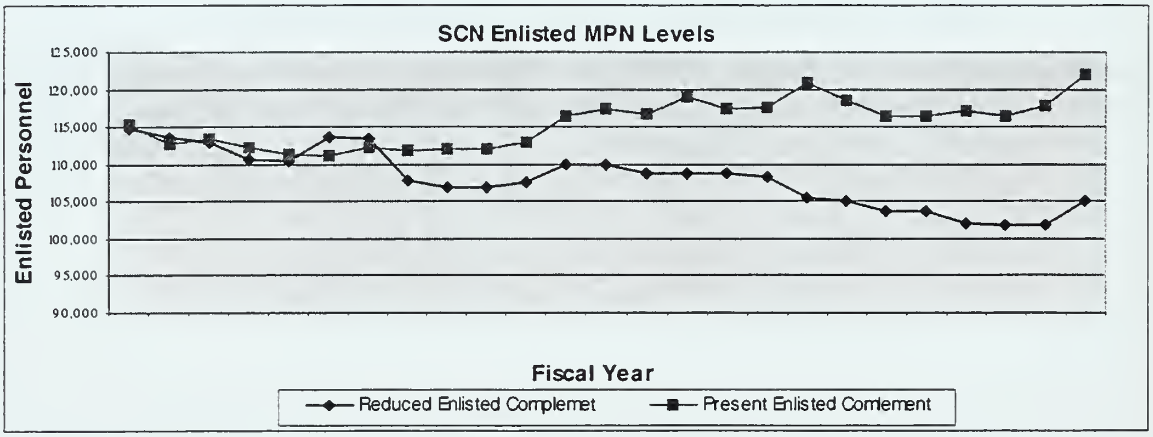

Figure 7 Base Case SCN Enlisted MPN Levels.

Enlisted SCN manpower levels for the base case force structure under the same two assumptions about manning on future ship classes applied to officer levels (Figure 6).

MPN costs for officers and enlisted personnel in the base case scenario are displayed in Figures 8 and 9.

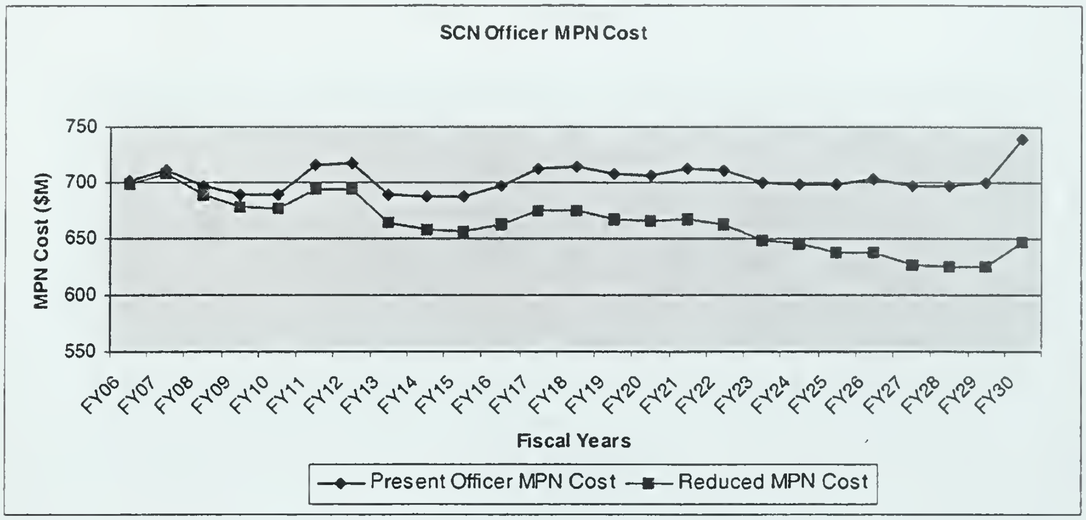

Figure 8 Base Case SCN MPN Cost for Officers.

MPN cost for the officer levels shown in Figure 6.

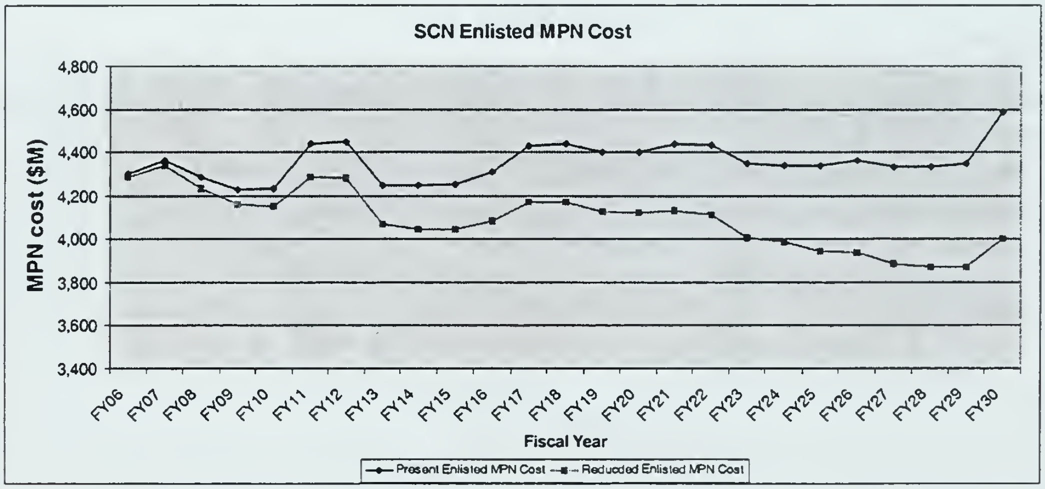

Figure 9 Base Case SCN Enlisted MPN Cost.

MPN cost for the enlisted levels shown in Figure 7.

Figures 10 and 11 show the APN manpower levels for the base case. Figure 12 displays the APN military personnel cost for the base case.

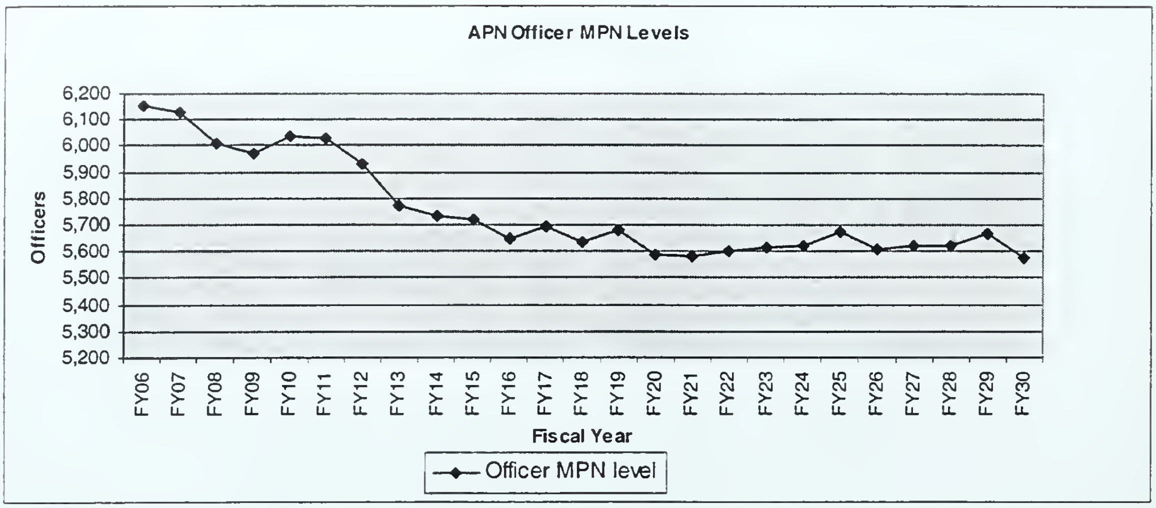

Figure 10 Base Case APN Officer MPN Levels

APN officer levels by year for the base case scenario. The downward trend reflects changing officer requirements for aircraft platforms intended for the same mission. For example, the EA-6B Prowler requiring four officers will start to be replaced by single seat F-18G starting in FY10.

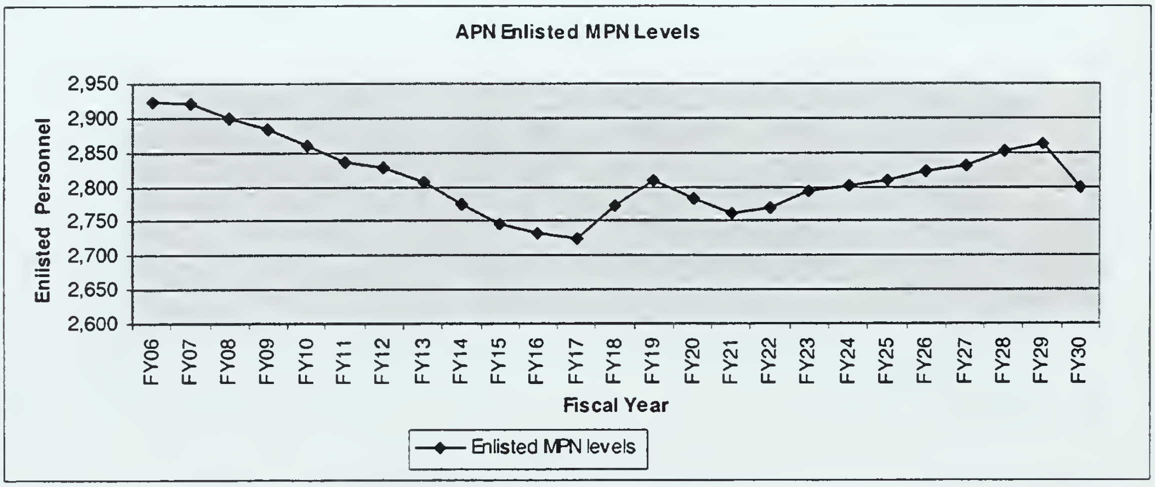

Figure 11 Base Case APN Enlisted MPN Levels

The fall and rise in APN enlisted levels is due primarily to the assumed manning requirements for aircraft procurement not modeled in GENSA.

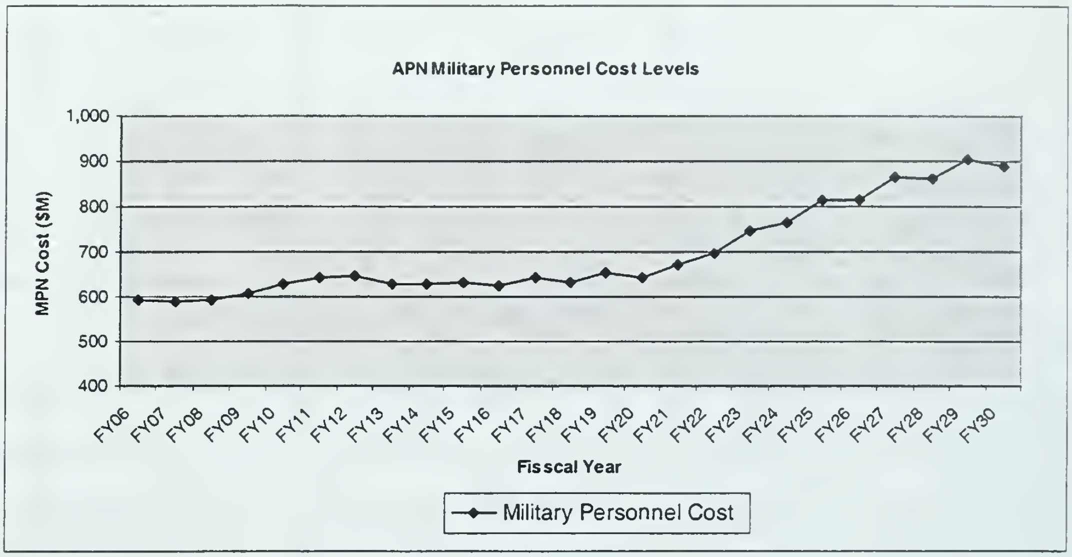

Figure 12 Base Case APN Military Personnel Cost Levels

There is a gradual increase in the APN military personnel cost.

2. A Dramatic Decrease In Budget

We reduce the upper and the lower TOA levels from 51,042.6 (FY00$M) and 34,684.6 (FY00$M) to 25,000 (FY00$M) and 20,000 (FY00$M) respectively. Observed mission deficiencies (summarized in Table 28) show a significant shortage in APN mission areas. We simply cannot satisfy all mission requirements under this budget cut.

Mission Areas \ Fiscal Years	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Destroyers							1				1		
Logistic AOE Ships	6	6	7	5	5	3	3	2	2	1	1	1	1
Fighter Aircraft	58	50	40	25					26	55	84	89	83
Attack Aircraft	1	1	1	1	5	9	17	25	35	44	53	65	75
ASW Aircraft Group 1						1	1	2	3	4		4	
ASW Aircraft Group 2	1	1	1	1	7	7	7	7	7	7	7	9	
Early Warning							3	3	4		3		3
Transport Aircraft													
UtilityAircraft													
Training Aircraft Group 1					1	1	1	2	2	2	2	2	2
Training Aircraft Group 2													
Training Aircraft Group 3						25	53	81	79	78	97	97	97
Rotary Wing Group 1													
Rotary Wing Group 2			7	42	61	80	68	56	31				

Mission Areas \ Fiscal Years	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
Destroyers												1
Logistic AOE Ships	1											
Fighter Aircraft	33	38	24	20	20	32	32	13	49	30	13	
Attack Aircraft	85	95	98	98	98	98	98	98	98	98	98	98
ASW Aircraft Group 1	6	12	7	1				4		8	15	20
ASW Aircraft Group 2	12		12				10		12	4	2	
Early Warning	7	10	15	18	13	9	4	8	11	15	18	20
Transport Aircraft	1	5	3		3	2		3		2	2	
UtilityAircraft				24	42	57	56	56	32	32	32	32
Training Aircraft Group 1	2	2	2	2	2			6	6	6	6	6
Training Aircraft Group 2						1	2	17	27	33	40	48
Training Aircraft Group 3	97	73	49	25	1	1	1	1	1	1	1	1
Rotary Wing Group 1				1	1					1	15	
Rotary Wing Group 2	1	4	7	10	13	16	19	22	25	28	31	34

Table 28 Budget Cut Excursion, Mission Deficits

Mission deficiencies result from a dramatically reduced budget band. Most SCN missions are satisfied but all of the APN mission areas are significantly affected. Figure 13 shows the fighter mission aircraft inventory levels and requirements.

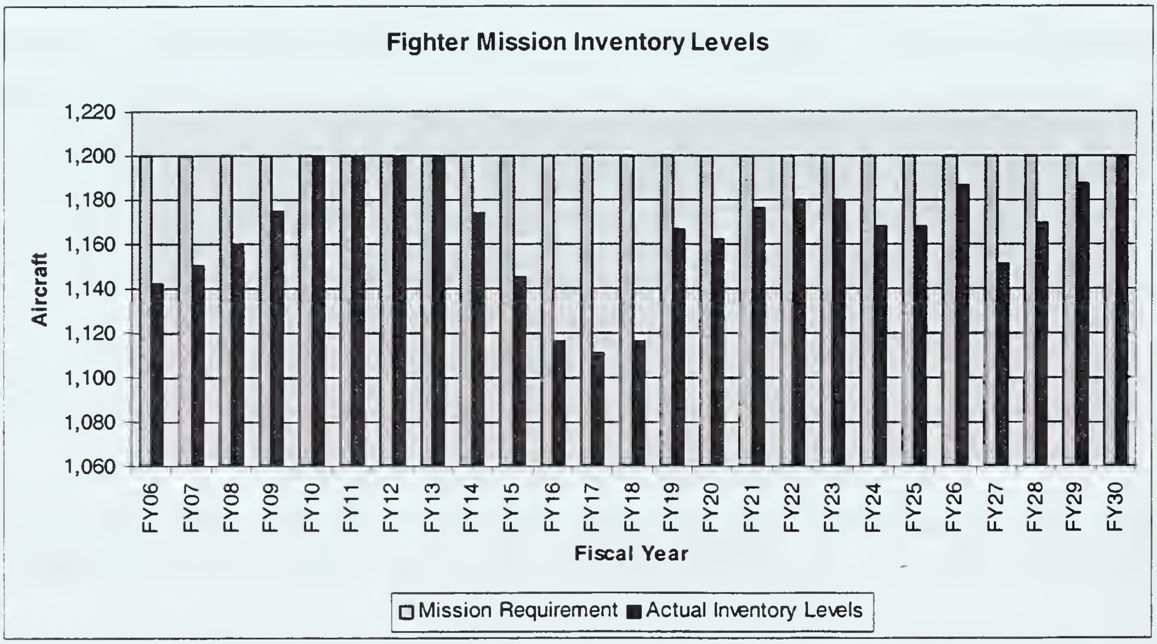

Figure 13 Budget Cut Fighter Mission Inventory Levels.

For the budget cut scenario the fighter mission inventory levels are met only in FY10, FY11, FY12, FY13, and FY30.

VI. CONCLUSION

We extended CIPA to include procurement of additional types of ships and aircraft and related OMN costs of all platforms derived from a detailed study of VAMOSC data. We also consider officer and enlisted manpower and manpower cost for recommended force structures.

N81 currently uses EPA/TOA, a spreadsheet-based decision support tool, for capital planning. EPA/TOA is a descriptive model, and given an input of a complete spending plan, EPA/TOA yields an accounting of the estimated long-run cost of this plan using generally accepted cost forecasting methods. Unfortunately, preparing a force structure scenario in EPA/TOA is labor-intensive work, so preparing many competing scenarios in search of long-range improvement is not feasible given the time pressure always governing this planning.

Capital Investment Planning Aid (CIPA) has been developed for N81 as an optimization-based decision support tool. Given an input of long-range force structure requirements, costs and rules governing candidate procurements and retirements of major weapons systems, and other planning guidance, CIPA suggests an optimal portfolio of investments and actions. CIPA has been prototypically demonstrated for a 25-year plan with a realistic subset of US Navy ships, submarines and aircraft, and a representative subset of budget funding categories.

GENSA, the subject of this study, extends CIPA to include additional Navy ship classes and aircraft types, and incorporates the Manpower Navy (MPN) funding category not considered by CIPA. GENSA has a planning horizon of 30 years, 29 mission areas, 45 ship classes, 30 aircraft types, and 13 production facilities. GENSA follows CIPA in recognizing cost categories SCN, APN, and OMN, and adds MPN. The goal of GENSA is to provide an omniscient long-term plan that considers so much high-fidelity detail that the post-optimization analysis with EPA/TOA will be much easier.

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APPENDIX. CUMULATIVE RETIREMENT GOALS FOR GENSA MODELED PLATFORMS

	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
F14	0	30	79	79	79	79	79	79	79	79	79	79	79
F18AB	16	17	17	17	22	27	43	87	123	172	184	184	184
F18EF	0	0	0	0	0	0	0	5	11	16	22	27	32
F18CD	17	37	37	66	101	133	154	171	208	260	311	356	409
EA6B	0	0	0	4	8	16	24	34	43	52	64	74	84
AV8B	0	0	0	0	12	20	28	37	45	53	59	67	74
S3B	0	0	0	5	6	6	7	8	9	15	21	28	34
P3C	0	0	0	6	6	6	6	6	6	6	6	6	11
E2C	0	0	0	0	0	6	6	7	10	14	18	22	26
C2AB	0	0	0	0	0	0	0	0	0	0	0	0	1
C12	0	0	0	0	0	0	0	0	0	0	0	0	0
T44	0	0	0	1	1	1	2	2	2	2	2	2	2
T45	0	0	0	0	0	2	4	7	9	11	14	16	18
T34	30	47	47	74	103	131	159	181	204	223	223	223	223
TH57	0	0	0	1	1	2	2	3	3	4	4	5	5
MV22	0	0	0	0	0	0	0	0	0	0	0	3	6
CH46E	27	33	52	71	90	113	137	148	148	148	148	148	148
CH53D	0	16	32	32	32	32	32	32	32	32	32	32	32

	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
F14	79	79	79	79	79	79	79	79	79	79	79	79
F18AB	184	184	184	184	184	184	184	184	184	184	184	184
F18EF	37	42	53	64	82	104	136	171	207	242	277	323
F18CD	451	468	468	468	468	468	468	468	468	468	468	468
EA6B	94	104	104	104	104	104	104	104	104	104	104	104
AV8B	81	96	125	145	145	145	145	145	145	145	145	145
S3B	40	47	53	59	65	71	77	84	93	100	105	105
P3C	16	27	38	49	69	75	97	118	140	150	161	171
E2C	29	34	37	40	44	47	51	54	58	61	63	63
C2AB	5	9	12	15	18	22	25	28	30	30	30	30
C12	1	1	27	45	60	83	83	83	83	83	83	83
T44	2	2	2	2	14	32	54	54	54	54	54	54
T45	20	22	24	26	31	44	59	69	75	82	90	99
T34	223	223	223	223	223	223	223	223	223	223	223	223
TH57	6	6	7	7	12	37	62	87	112	126	126	126
MV22	9	12	15	18	21	24	27	30	33	36	39	41
CH46E	148	148	148	148	148	148	148	148	148	148	148	148
CH53D	32	32	32	32	32	32	32	32	32	32	32	32

Table 29 Cumulative retirement requirements of aircraft in GENSA.

	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26
FFG	0	0	1	4	4	7	10	13	16	19	22	25	28	30	30	30	30	30	30	30	30
DDG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DDGX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DD	3	6	10	10	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
DD21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	7	10	13	16	19
CG21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CVX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CVN68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
CVN63	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
CVN65	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SSBN726	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSBNX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSN774	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSN21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSN688	1	2	3	4	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	35	38
SSNX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LHX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LHA	0	0	0	0	0	1	1	2	3	4	4	4	5	5	5	5	5	5	5	5	5
LHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LSD36	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LSD41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
LSDX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPD4	0	2	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MCM1	0	0	0	0	0	0	0	0	0	1	1	3	5	7	9	11	13	14	14	14	14
MCMX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHC51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
MHCX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LCC19	0	0	0	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
LCCX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AO187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5
TAOX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AOE1	0	0	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AOE6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TADCX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
ASX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARS50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ARSX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATF166	0	0	0	0	0	1	3	5	6	7	7	7	7	7	7	7	7	7	7	7	7
TATFX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TAGOS1	0	0	0	0	0	0	0	0	0	0	1	1	2	3	3	3	3	3	3	3	3
TAGOS19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	4
TAGOS23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 30 Cumulative retirement requirements of ships and submarines in GENSA.

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